High Impact Strength, Elastic, Composite, Fibre, Metal Laminate

FIELD OF THE INVENTION

A Novel High Impact Strength, Elastic ELACO™ (ELAstic COmposites) Fibre Metal Laminate Structure represents a new approach in damage tolerant design philosophy having a first and second outer face layer for forming an outer face (4), a first and second ply (2), and a dissipating element (1) and polymer matrix (3).

The dissipating elements (1) are various any metal and non-metal structures (expanded metal, ornamesh, rigidised metal, corrugated sheet, tube, balls, and any other similar forms, aluminium foam or other metallic foam-like structures) having the function of dissipation and redirection of local active loading (impact) applied to at least one of the two outer faces, to longitudinal (tensile) reactive loading in fibre reinforcement-inner plies.

The outer plies (2) are constructed from a variety of reinforcement materials (Glass, Aramid, Carbon fibre, and any other single or hybrid sorts), in combination with variety of any known thermosetting and thermoplastic matrixes (3): Vinylester, Epoxy, Phenolic, Polypropylene, Nylon, fire retardant, corrosion resistant, any sort of adhesives, coatings and pigments.

The outer face layers (4) are made from a variety of any metallic and non-metallic materials.

BACKGROUND OF THE INVENTION

The elastic properties of continuous and unidirectional fibrous composites are highly anisotropic and depend of fibre orientation with respect to the applied stress. The axial tensile strength of a unidirectional lamina is typically controlled by the fibre ultimate strain. The transversal tensile strength of a unidirectional lamina is mainly controlled by the matrix ultimate strain. The strength of a fibre reinforced structure is at least an order of magnitude greater in the longitudinal direction than in the transversal/perpendicular direction to the fibre main axis.

In comparison with traditional structural materials the Novel High Impact Strength, Elastic ELACO™ Fibre Metal Laminate group offers a unique combination of mechanical strength, especially during extreme loading, (impact), with significant weight reduction in comparison with similar samples made from steel or aluminium.

In comparison with already known/existing composite structures whose major disadvantage is brittleness, Novel High Impact Strength, Elastic ELACO™ Fibre Metal Laminate offers high impact resistance with exceptionally high levels of elasticity and elastic recovery after plastic deformation.

Novel High Impact Strength, Elastic ELACO™ Fibre Metal Laminate structure is made from cost-effective and standard materials and exhibits significant proven improved mechanical properties in comparison with all existing fibre-metal laminates. Its properties include:

- high impact strength,
- high energy-absorbing ability,
- high elasticity under impact,
- high percentage of elastic recovery during plastic deformation,
- internal force/impact energy dissipation in the direction of the fibre reinforcements,
- low density,
- high tensile strength in all directions,
- high fatigue resistance and durability,
- simple and cost-effective machining and fabricating.

The feature common to all polymeric composite processes is the combining of a resin, a curing agent, some type of reinforcing fibre, and, in some cases, a solvent. Typically, heat and pressure are used to shape and "cure" the mixture into a finished part. In composites, the resin acts to hold the fibres together and protect them, and to transfer the load to the fibres in the fabricated composite part. The curing agent, also known as hardener, acts as a catalyst and helps in curing the resin to a hard plastic. The reinforcing fibres impart strength and other required properties to the composite.

Production of Novel High Impact Strength, Elastic ELACO™ Fibre Metal Laminates includes all known processes in composite manufacturing such as:

1. Hand lay-up

The hand lay-up technique is one of the oldest, simplest and most commonly used methods to manufacture composite, or fibre-reinforced, products.

The product is trimmed and laid down over a mould where it is formed to the desired shape. Several layers may be required. Resins are impregnated by hand into fibres which are in the form of woven, knitted, stitched or bonded fabrics. This is usually accomplished by rollers or brushes, with an increasing use of nip-roller type impregnators for forcing resin into the fabrics by means of rotating rollers and a bath of resin. Laminates are then left to cure under standard atmospheric conditions.

Materials Options:

Resins: Any, e.g. epoxy, polyester, vinylester, phenolic.

Fibres: Any, although heavy aramid fabrics can be hard to wet-out by hand.

Cores: Any.

Main Advantages:

i) Widely used for many years;

ii) Simple principles to teach;

iii) Low cost tooling, if room-temperature cure resins are used;

iv) Wide choice of suppliers and material types; and

v) Higher fibre contents, and longer fibres than with spray lay-up.

2. Vacuum Bagging

This is basically an extension of the wet lay-up process described above, where pressure is applied to the laminate once laid-up in order to improve its consolidation. This is achieved by sealing a plastic film over the wet laid-up laminate and onto the tool. The air under the bag is extracted by a vacuum pump and thus pressure of up to one atmosphere can be applied to the laminate to consolidate it.

Materials Options:

Resins: Primarily epoxy and phenolic. Polyesters and vinylesters may have problems due to excessive extraction of styrene from the resin by the vacuum pump.

Fibres: The consolidation pressures mean that a variety of heavy fabrics can be wet out.

Cores: Any.

Main Advantages:

i) Higher fibre content laminates can usually be achieved than with standard wet lay-up techniques.

ii) Lower void contents are achieved than with wet lay-up.

iii) Better fibre wet-out due to pressure and resin flow throughout structural fibres, with excess into bagging materials.

iv) Health and safety: The vacuum bag reduces the amount of volatiles emitted during cure.

3. Autoclave moulding

Maximising performance of thermoset composite materials requires, amongst other things, an increase in the fibre to resin ratio and removal of all air voids. This can be achieved by subjecting the material to elevated pressures and temperatures. As described in the vacuum bagging section, some pressure can be exerted by applying a vacuum to a sealed bag containing the resin/fibre lay-up.

However, to achieve three dimensional, uniform pressures of greater than 1 bar, additional external pressure is required. The most controllable method of achieving this for an infinite variety of different shapes and sizes is by applying a compressed gas into a pressure vessel containing the composite lay up. In practice, this is achieved in an autoclave.

To achieve internal active force/impact energy dissipation in Novel High Impact Strength, Elastic ELACO™ Fibre Metal Laminate (Figure 1.) various metallic and non-metallic structures may be used as dissipating elements: expanded, ornamesh, rigidised forms, corrugated sheets, tubes, balls, aluminium foam or other metallic foam-like structures and any other similar forms (2), and include but are not limited to one or more elements selected from the following metallic and non-metallic material

groups such as: aluminium alloys, steel alloys, zinc alloys, titanium alloys, copper alloys, magnesium alloys, nickel alloys, aluminium alloy matrix composites, thermoplastics, plastics, polymers foams, wood, rubber.

As a result of loading redirection/dissipation, there are now tensile-reactive forces/loadings in reinforcement plies and based on mechanical properties of fibre reinforcement materials, where the tensile strength of reinforcement materials is at least an order of magnitude higher than transversal strength, the result is the significantly higher strength of the new ELACO™ structure.

With application of this invention, the impact resistance of the Novel High Impact Strength, Elastic ELACO™ Fibre Metal Laminate does not depend mainly on the matrix's (3) properties; it is now directly dependable on the fibre reinforcements' mechanical properties.

With respect to orientation these internal dissipating elements may be arranged as: unidirectional, cross-ply, symmetric, balanced, quasi-isotropic.

As components in the manufacturing of a diverse variety of Novel High Impact Strength, Elastic ELACO™ Fibre Metal Laminates may use any single or hybrid known reinforcement fibres that are made from one or more materials selected from the groups consisting: E-glass, R- glass, S2-glass, aramids, carbon and hybrid fibre reinforcements (2) as Quadriaxial, Unidirectional, Double-bias, Biaxial, Triaxial, Plain woven, Woven rovings, with use of any known matrixes (3): Vinylester, Epoxy, Phenolic, fire retardant, corrosion resistant resins, and any sort of adhesives, coatings and pigments .

With respect to orientation, reinforcement plies may be arranged as: unidirectional, cross-ply, symmetric, balanced, quasi-isotropic and hybrid laminates.

Outer face layers (4), whether for protective or decorative purpose, may be one of the metallic and non-metallic materials such as: aluminium alloys, steel alloys, zinc alloys, titanium alloys, copper alloys, magnesium alloys, nickel alloys, alloy matrix composites, wood, plastics, rubber, paper, thermoplastics, polymers, foams, rubber.

The Novel High Impact Strength, Elastic ELACO™ Fibre Metal Laminate may include structures based on a variety of metallic and non-metallic materials such as: foams, wood, rubber, honeycomb structures, thermoplastics, plastics, ceramics, polymers, hybrid sandwiches, paper.

The Novel High Impact Strength, Elastic ELACO™ Fibre Metal Laminates may be manufactured and used in a variety of applications in combination with any metallic and non-metallic materials, such as: honeycomb structures, wood, foam, thermoplastics, ceramics, plastics, hybrid sandwiches, rubber.

Nanostructures may be formed as described above, with substitution of expensive materials such as boron and others, with materials mentioned, to reduce current high prices and make them widely available to industry.

The fabrication process of the Novel High Impact Strength, Elastic ELACO™ Fibre Metal Laminate includes two additional operations that consist of:

- preparation (cleaning/anodising) of structures used as a dissipating element; and

- implementation of one or more internal dissipating elements in new ELACO™ Laminates as well as in other composite structures.

As the second stage of fabricating parts/structures with the use of new ELACO™ Laminates, the following processes may be used most of technologies used in metal and plastics forming processes such as: moulding, stamping, technologies used in cold deformation forming processes such as: blanking, punching, flanging, embossing, bending, drawing.

Primary and secondary structures designed, created and manufactured on the basis of Novel High Impact Strength, Elastic ELACO™ Fibre Metal Laminate idea-invention, can be used in the:

- aviation industry (civil and military),
- space industry (civil and military),
- train and rail industry (civil and military),
- maritime industry (civil and military),
- automotive industry (civil and military),
- all sorts of building industry (civil and military),
- protective industry/ballistic (civil and military),
- construction industry, decoration, machinery, furniture and municipal engineering, road-side safety barriers, and simmilar,
- multiple general applications,
- materials developed through nanotechnology.

EXAMPLES

For example, measured and calculated average properties of Novel High Impact Strength, Elastic ELACO™ Fibre Metal Laminate sample made from two outer layers of E-Glass quadriaxial woven fibre 1200 gr/m2, one internal/dissipation element: Aluminium Ornamesh Type R, and Vinylester resin DERAKANE 411-350, are:

- Tensile Strength $\sigma > 1000$ MPa,

- Density $\rho = 2247\ kg / m^3$,

- Peak Impact Force F = 184.3 kN (without penetration),

- Impact Energy Absorbed $E_A = 3985$ J (without penetration),

- Deflection 41 mm,

- Young's modulus of elasticity E = 33 GPa,

- Poison's ratio $\nu = 0.33$.

Table 1. Comparison of selected mechanical properties of materials now in use in the automotive and aviation industries with the Novel High Impact Strength, Elastic ELACO™ Fibre Metal Laminates

Materials	hickness [mm]	Specific Weight [kg/m^3]	Veight per 1m^2 kg/m^2]	Absorbed Impact Energy [J]	Specific bsorbed Impact Energy/Weight [J/kg]	Deformation [mm]	Peak Force [kN]	Tensile Strength [MPa]
Aluminium	1.5	2750	4.13	0	0	perforated	-	485
Steel	0.8	7850	6.28	0	0	perforated	-	655
Steel	1.5	7850	11.78	4272	1453	69	133.4	655
Honey.Comp.	4.3	1220	5.25	-	-	perforated	-	-
Glare-5	2.0	2590	5.18	150	-	perforated	10.3	-
ELACO™ 1	2.9	2247	6.51	3985	1510	41	184.3	>1000
ELACO™ 2	5.0	1934	9.67	3778	1108	13	153.9	>1000
ELACO™ 6	15.2	1304	19.82	3919	688	29	176.0	>1000
DYN 1	-	-	-	3727	-	perforated	91.7	-
DYN 5	-	-	-	4100	-	perforated	69.9	-

Legend:
- Data for Glare-5, "Application of Fibre-Metal Laminates", Polymer Composites, August 2000, [Absorbed Impact Energy (maximum) before Perforation],
- Data for DYN 1, and DYN 5 (Structures based on Kevlar reinforcements), form "Impact Testing in Formula One", A. N. Mellor, (Absorbed Impact Energy within displacement of 100 mm) Transport Research Laboratory, Crowthorne, England, ("ICRASH 2002" International Conference, February 2002, Melbourne),
- ELACO™ – Novel High Impact Strength, Elastic ELACO™ Fibre Metal Laminate Structures.

Samples (Aluminium, Steel and ELACO™) were rigorously tested on a controlled drop weight impact tower with an impactor made from solid steel, weighing 45 kg. The impactor head was formed as a ball of diameter 200 mm. Sample dimensions was 500x500 mm. The speed of the impactor at the moment of impact was 55 km/h.

The comparison between Steel sample thickness 1.5 mm and sample ELACO™ 1 ***(Table 1)***, shows that the level of impact energy absorbed by ELACO™ 1 is 93% greater than the impact energy absorbed by the Steel sample with 40% lower deflection after impact. At the same time, the weight reduction between ELACO™ 1 and Steel 1.5 mm is more than 100%.

In comparison with Steel 1.5 mm sample, ELACO™ 2 shows high level of elasticity, superior deflection reduction with significant weight reduction. Deflection of ELACO™ 2 is only 20% of deflection recorded by the Steel sample, with 88% of impact energy absorbed of these absorbed by the Steel sample.

Use of the Novel High Impact Strength, Elastic ELACO™ Fibre Metal Laminates delivers highly controlled and predictable behaviour under load, accompanied by:

- manufacturing costs can be minimized since known and established manufacturing processes are used;

- significant finished-product weight reduction;
- demonstrated increases in mechanical properties through its substitution for heavier (steel and aluminium) and more expensive metals;
- expected improved fatigue resistance;
- low maintenance and repair costs;
- the possibility of innovative cost-saving solutions to design problems now limited by the necessity to use conventional heavier metal sheeting;
- the possibility to manufacture complex sections with reduced number of primary parts in an assembly.

The desirable properties of the Novel High Impact Strength, Elastic ELACO™ Fibre Metal Laminates give their user a unique opportunity to create structures exhibiting easily replicated, tightly controlled behaviour under a wide range of loads, especially under extreme impact loading.

The physical properties of the Novel High Impact Strength, Elastic ELACO™ Fibre Metal Laminates could be widely varied and precisely tailored to the needs of the particular end use application by combining various sorts of materials in creating new structures.

The result of all above mentioned is an opportunity of global implications for the application and further development of high-tech, high-impact strength, cost-effective, new products and components for everyday use in manufacturing, transport, packaging and industry in general.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1. is a fragmentary cross-sectional view of a Novel High Impact Strength, Elastic ELACO™ Fibre Metal Laminate with tubes as dissipating elements.

Figure 2. is a fragmentary cross-sectional view of a Novel High Impact Strength, Elastic ELACO™ Fibre Metal Laminate with corrugated sheet as dissipating elements.

Figure 3. is a fragmentary cross-sectional view of a Novel High Impact Strength, Elastic ELACO™ Fibre Metal Laminate with ornamesh/rigidised form as dissipating elements.

Figure 4. is a graph showing the relationship between sample weight and impact energy absorbed.

Figure 5. is a graph showing weight comparison between samples.

DETAILED DESCRIPTION OF A PREFERRED EMBODIMENT

Figure 1. illustrates basic principles of internal force-impact energy dissipation and redirection of local active loading (impact) [F] applied to at least one of the two outer faces of the new structure, to longitudinal (tensile) reaction [F_i] in fibre reinforcement plies. These forces are forming force equilibrium as shown on Figure 1. Figure 1. shows an example of the new ELACO™ structure (ELACO™ 7) where the tubes (1) are dissipated elements.

Figures 2. and 3. show another two examples where applied various metal structures (expanded metal, ornamesh, rigidised forms, corrugated sheets), as the dissipated elements (1), can redirect outer active force/impact energy [F] to the face of the structure, to the longitudinal force/reaction [Fi] in the reinforcement plies (2).

Figure 3. shows very high consistency of impact energy absorbed by new ELACO™ samples.

Figure 4. shows significant specific weight reduction of new ELACO™ materials in comparison with steel and aluminium.

Although particular preferred embodiments of the invention have been disclosed in detail for illustrative purposes, it will be recognised that variations or modifications of the disclosed invention, including the use of various materials in creating Novel High Impact Strength, Elastic ELACO™ Fibre Metal Laminates lie within the scope of the present invention.